# Assessing Water Quality Functions of Wetlands

*by Steven L. Ashby*

**PURPOSE:** This technical note provides an overview of the current understanding of water quality functions of wetlands and describes methods useful for assessing water quality functions. This technical note is specifically oriented to provide direct assistance in the assessment of water quality functions of wetlands. There is an abundance of literature on the nature and function of wetlands for additional information (e.g., Mitsch and Gosselink 1993; Lugo, Brinson, and Brown 1990; Kadlec and Knight 1996; Hammer 1989). Both qualitative and quantitative assessment methods are discussed and the need for good hydrology information is emphasized for quantitative assessment methods. Two case studies are summarized in a generic format to offer ideas on methods to assess water quality functions. Information from the Corps of Engineers' Water Quality Research Program, Water Operations Technical Support Program, Wetlands Research Program, Wetlands Research Technical Center, and the Wetlands Research Assistance Program is also available at *http://www.wes.army.mil/el/.*

**BACKGROUND:** Water quality processes and water quality functions of wetlands are not easily defined terms. Water quality processes are often described by measurements of physicochemical constituents that are usually of interest to a particular group or are determined to be relevant to a particular site. These particular constituents have temporal and spatial components, are directly linked to the watershed and activities within the watershed, and linked to hydrology, geology, and biology (e.g., microbial and vegetative processes). Water quality functions are often considered as an accumulation or summation of various water quality processes. For example, the water quality process of denitrification can be considered as a water quality function of nutrient (nitrogen) removal. General water quality functions, effects, social values, and indicators, as summarized by the National Research Council (1995), are presented in Table 1.

**Table 1**
**Water Quality Functions, Effects, Society Values, and Relevant Indicators**

| Function | Effects | Society Value | Indicator |
|---|---|---|---|
| Retention or removal of imported material | Reduced transport of nutrients downstream | Maintenance of water quality | Nutrient outflow lower than inflow |
| Accumulation of peat | Retention of nutrients, metals, and other substances | Maintenance of water quality | Increase in depth of peat |
| Accumulation of inorganic material and sediments | Retention of sediments and some nutrients | Maintenance of water quality | Increase in depth of sediment |

In general, sediment and toxicant retention, nutrient removal, retention, or transformation, and production export (the effectiveness of the wetland to produce food or usable products for humans or other living organisms, e.g., fisheries, organic carbon export) comprise the water quality functions for purposes of this report. Considerations and qualifiers for these three functions are summarized below with information from methodology provided by the U.S. Army Corps of Engineers (1995).

Figure 1 is an overview of water quality processes and zones for material exchange. General requirements for sediment and toxic retention include a potential source in the watershed, opportunity for trapping in the wetland, fine-grained or organic material present in the wetland, and opportunity for aerobic and anaerobic processes. Site hydrology and type and extent of vegetative cover also play a critical role in the ability of a wetland to retain sediments and toxicants. Requirements for nutrient removal, retention, and transformation are similar to those of sediment and toxicant removal and may also be positively related to a large wetland relative to the size of its watershed. Vegetation density and ability to utilize nutrients and site hydrology are both critical to nutrient removal, retention, and transformation. Requirements for production export include growth of wildlife food sources within the wetland, development of detritus, economically or commercially used products present in the wetland, use by wildlife and higher trophic level consumers, presence of fish or shellfish, dense vegetation, diverse plant community structure, and export of nutrients and organic material. However, it must be pointed out that it is very difficult to separate out individual functions and values, since they are interrelated.

Assessing or measuring water quality functions is also difficult and often compounded by site hydrology in natural, disturbed, and constructed systems. Brinson (1995) notes that there is a tendency to view individual wetlands as bundles of functions rather than internally complex and highly integrated ecosystems and the same could be stated for water quality functions of wetlands.

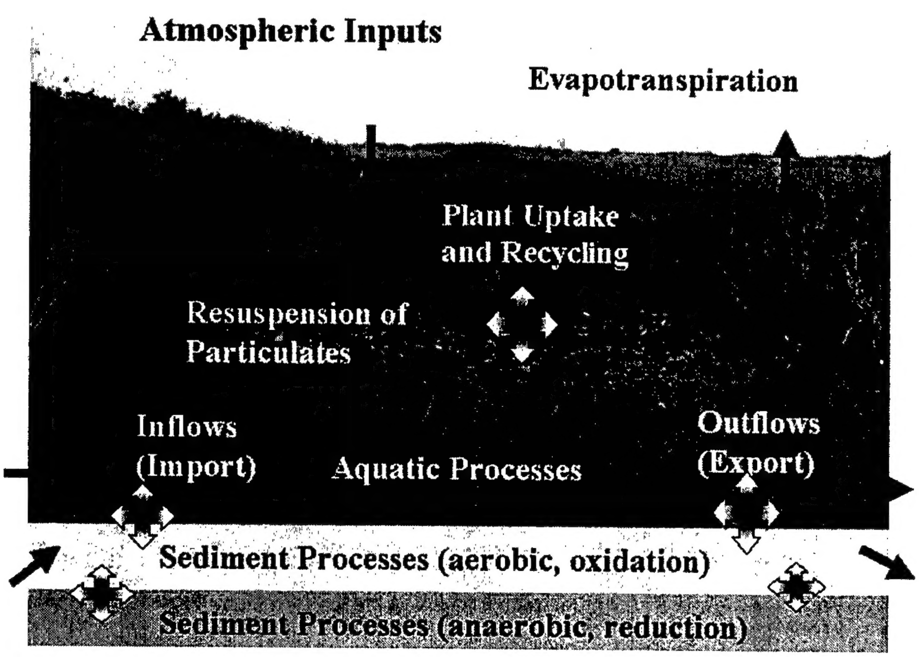


Figure 1. Overview of water quality processes and functions in wetlands

**ASSESSING WATER QUALITY FUNCTIONS OF WETLANDS:** Bartoldus (1999) provides an excellent review of 40 wetland assessment procedures. Of the 40 methods reviewed, 27 methods included water quality assessment procedures to some extent. In general, most of these methods use a ranking method often combined with weighting and are typically intended for rapid application. This approach often uses easily obtained information that suggests potential or opportunity for water quality functions (e.g., source of pollutant in the upstream watershed, detention time, ponds, etc.). Only a few methods offer a more quantitative approach but typically require more effort (e.g., time, money, expertise) to apply. Some of the more recently developed methods have also been evaluated and categorized as logic or mechanistic by Hruby (1999). Hruby points out that the current rapid assessment methods do not assess rates or dynamics of ecological processes occurring in wetlands but they do allow a way of organizing current knowledge, including subjective observations. Three general criteria were common to the methods reviewed:

- An image of characteristics found for the highest performing wetland was compared to the ideal.
- Reference standards for each function in a region were used for comparison.
- The least altered reference in a region (reflecting the highest performance for all functions) becomes the standard.

**QUALITATIVE APPROACHES:** Walbridge (1993) provides a good discussion of the water quality functions of forested wetlands. The discussion describes improvements to water quality as related to biogeochemical processes (denitrification, phosphate sorption, nutrient uptake, decomposition of organic material, sorption of heavy metals, and retention of toxics) and sediment deposition. Denitrification is considered to be the most important mechanism of nitrogen removal in southern forested wetlands (Walbridge 1993; Day, Butler, and Conner 1997; Brinson, Bradshaw, and Kane 1984; Lowrance et al. 1984; Jacobs and Gilliam 1985). Walbridge (1993) also lists other mechanisms of nitrogen removal including plant uptake (Lowrance et al. 1984), microbial immobilization (Qualls 1984), and the accumulation of ammonium on cation exchange sites (Brinson, Bradshaw, and Kane 1984). Removal of phosphorus in southern forested wetlands is accomplished by uptake by plants, microbial immobilization, sediment deposition, and adsorption to clay sediments according to Walbridge (1993) and as described in Kitchens et al. (1975); Day, Butler, and Conner (1977); Mitsch, Dorge, and Wiemhoff (1979); Yarbro (1983); Brinson, Bradshaw, and Kane (1984); Lowrance et al. (1984); and Richardson, Walbridge, and Burns (1988). Walbridge (1993) concludes that sediment and nutrient removal and transformation in southern forested wetlands may provide the greatest value to society of these types of systems, particularly when they are located along low-order streams.

Atkinson et al. (1993) suggested that using plot-weighted averages of vegetation, classified as either wetland or upland species, might be an effective way to provide early estimates of success of created wetlands. The approach provides a relatively easily applied method, as long as knowledgeable wetland botanists are available to assess the site, and can be compared to a reference system. Sufficient monitoring can provide a trajectory to estimate time to complete vegetative coverage. The approach does not provide a measure of wetland functions but assumes that the types of plants present are indicators of hydrology and soil conditions. The approach is not reasonable for setting mitigation ratios (Atkinson et al. 1993) but may be useful in monitoring success and indicate a need to modify management of the mitigation site.

**REFERENCE WETLANDS:** In an example of applying wetland reference data to functional assessment in mineral soil wet flats, Rheinhardt, Brinson, and Farley (1997) describe the model used in the Hydrogeomorphic (HGM, Brinson (1993)) assessment approach to evaluate water quality functions (e.g., maintain characteristic nutrient and elemental cycling processes). The authors acknowledge the constraints of conducting extensive data collection efforts and provide an alternative rapid assessment method that allows calculation of an Index of Function for the HGM utilizing easily measured variables (e.g., snag density, volume of coarse woody debris, mean litter depth, basal area of trees, subcanopy density, percent cover of trees and shrubs, and percent cover of graminoids and forb (non-graminoid herbs). The relationship of these variables to those of reference conditions allows establishment of the extent of impact. This approach assumes that the measured variables are good indicators of nutrient processing.

**QUANTITATIVE APPROACHES**: Hydrology is probably the most important factor for determining the establishment and maintenance of specific wetland functions (Mitsch and Gosselink 1993) and is critical to any quantitative approach used to assess water quality functions. An excellent overview of hydrology in freshwater wetlands is provided in Gosselink and Turner (1978). A general conceptual model of the role of hydrology in wetland ecosystems (Gosselink and Turner 1978) includes solar radiation, temperature, precipitation, relative humidity, and cyclic regularity as forcing functions on hydrology, chemical and physical properties of the substrate, the biotic ecosystem response and the interactions between them, and accumulation of organic matter and modifications to hydrology, all within a local climate regime. Water, nutrients, toxins, and oxygen availability are considered by Gosselink and Turner (1978) to be the four major chemical and physical properties of the substrate that are influenced by the hydrologic regime and appear to limit ecosystem development. Using Figure 1, sources of water include precipitation and relative humidity directly available to the site, inflow from offsite sources (runoff), and groundwater. Losses of water are attributable to evapotranspiration and outflows (surface and groundwater). Water is also stored temporarily in the vegetation and on the site (both in surface and sub-surface storages).

Water movement into and out of a wetland system also provides opportunity for import and export of material (see Figure 1). Measuring both the amount of water coming into and leaving a wetland system, along with concentrations of water quality constituents of concern (e.g., sediments, nutrients, toxicants, and organic carbon) allows for a quantitative method of material retention or transport that can be used to describe water quality functions. While initially this approach seems relatively straightforward, difficulties and expense associated with measuring water movement and accounting for all sources and sinks of water (i.e., the water budget) and material movement (e.g., selected water quality constituents and associated processes and transformations) limit the extent to which this approach can be used. Figure 2 provides a general schematic or conceptual model for the mass balance approach to quantitatively assess water quality functions of wetlands. Wetland hydrology is discussed in more detail in Kadlec and Knight (1996).

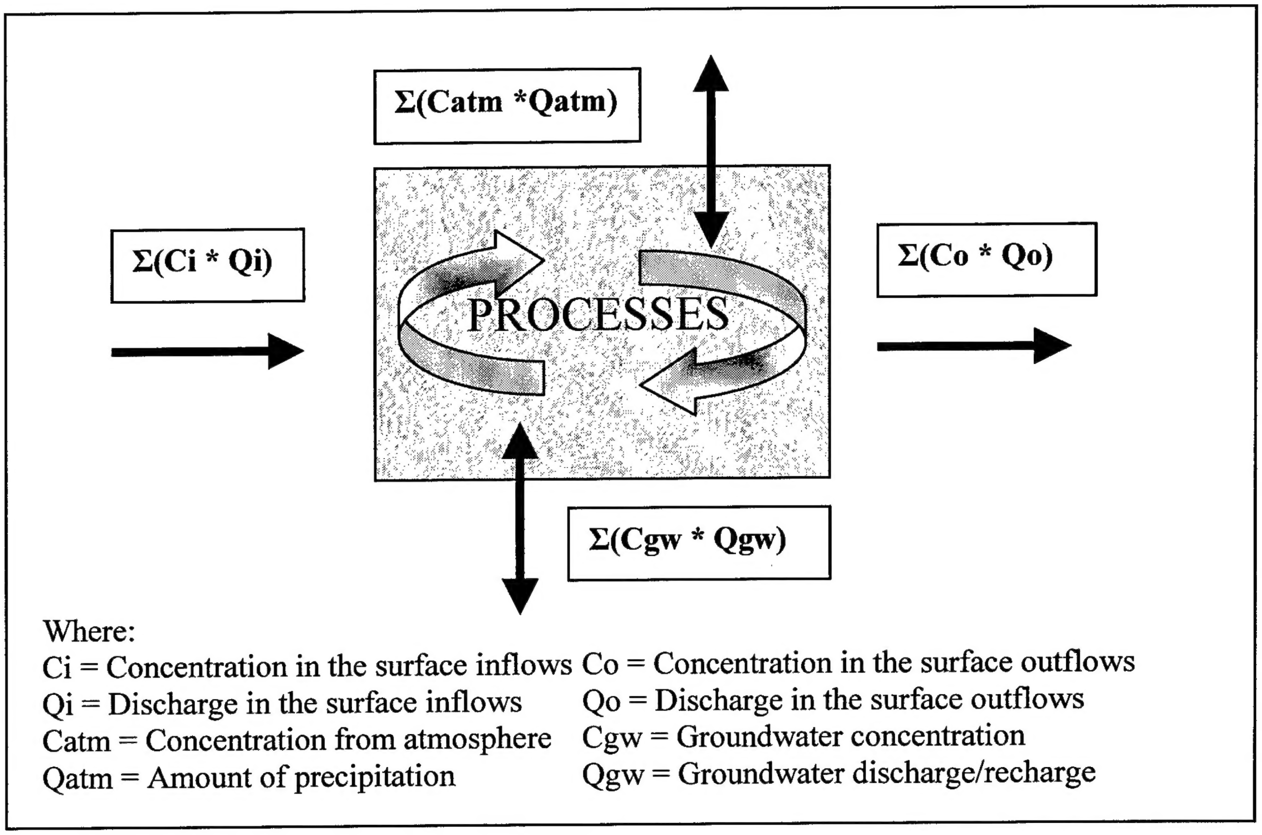


Figure 2. Conceptual model for mass balance approach for quantitatively assessing water quality functions of wetlands

Methods for measuring discharge into and out of an aquatic system typically employ the measurement of water current (velocity, $v$) using calibrated meters and discharge ($Q$) is calculated as a function of the cross-sectional area ($A$) of the stream.

$$Q = A * v_{(avg)}$$

In most cases, multiple measurements of velocity are used across the stream in conjunction with depth profiles to obtain a more accurate estimate of the total discharge.

The mass balance approach (as depicted above) attempts to account for major import and export of water and material in the system without any detail to internal processing of material. Sampling or monitoring using this approach needs to account for spatial and temporal (seasonal) variability in water movement, biogeochemical processes, and seasonal succession of the vegetation. Emphasis should be placed on events that result in major water and/or material transport (e.g., snowmelt runoff and major runoff events). Consideration should be given to processes such as atmospheric deposition and denitrification, which are often overlooked or omitted due to financial constraints. Murray and Spencer (1997) provide a good overview of the use of material budgets in describing material movement (particularly for tidal wetlands) and caution about the use of limited measurements to extrapolate to annual values.

**MODELING:** Due to the difficulty in quantifying nutrient input and productivity, very few water quality (e.g., energy-nutrient) models have been developed for wetlands (Mitsch and Gosselink 1993). Hydrologic complexities of wetlands also make modeling the water budget, necessary for mass balance models, very difficult. Using information from constructed wetlands, which typically have very good control of the hydrology of the system and material input and export, Dortch and Gerald (1995) have developed a screening-level model (PREWET) for estimating pollutant removal. This model assumes steady-state conditions for the wetland (i.e., flow and concentrations are constant in time) and quantitatively expresses pollutant removal in terms of removal efficiency (RE) using the following equation:

$$RE = 100 \times \frac{W_L - QC}{W_L}$$

where

$W_L$ = total loading of pollutant entering the wetland
$Q$ = total water flow rate exiting the wetland
$C$ = pollutant concentration of flow exiting the wetland

Thus, $RE$ = 100 percent would denote the total removal of a pollutant. The model considers hydraulic residence time and biogeochemical processes (via literature-based values for determining coefficients) but more sophisticated modeling is required for site-specific applications where hydrology is more complicated and detailed biogeochemical processing is desired. Concepts from screening-level models, such as PREWET, can be useful for assessing more complex systems, but the effort and cost associated with data collection and development/application of more sophisticated models should be considered.

**CASE STUDIES:** Water quality assessments are conducted for a variety of reasons, usually focused on material retention associated with constructed wetlands or on measuring processes in natural or disturbed wetlands. A variety of approaches are used and application of the data varies from general assessments of water quality functions to detailed process descriptions. Given the difficulty in conducting detailed assessments to quantify water quality functions, empirical or conceptual approaches are often used. Two approaches, one large-scale and one site-specific, are summarized below.

**Large-scale Assessment.** One of the major difficulties in large-scale assessments is typically a lack of sufficient site-specific data to describe temporal and spatial patterns for a diverse study area. One approach to this dilemma is to compile and evaluate all of the relevant, existing data for the area and supplement with additional data collection if possible. Typically, the collection of additional data is limited by time, money, and other resources, so the use of existing data is the primary option. In the absence of sufficient site-specific data, surrogate information is used (e.g., literature-based information or information from reference wetlands). In an attempt to evaluate the impacts of a project on land use in approximately 38,000 acres in the New Madrid Floodway and St. Johns Bayou, an approach was developed to determine the relative change in material processing associated with changes in flooding regimes on various land uses and project alternatives (Ashby, Ruiz, and Deliman 2000). In this approach, water quality data were retrieved from national databases such as EPA's Storage and Retrieval System and the USGS National Water Quality

Assessment Program. These data were then evaluated and average concentrations for nitrogen, phosphorus, carbon, and suspended solids were applied to volumes of water at specific elevations associated with various project alternatives. These mass values were then "processed" based on a range of removal or transport values for various wetland types in the literature, runoff coefficients for non-wetland land covers, and various sources of floodwaters based on different project scenarios. Removal or transport was then estimated for each constituent (e.g. nitrogen, Figure 3). The approach incorporated a simple spreadsheet, geospatial data on land cover type and area inundated at various elevations, and water volumes for each land cover area at various elevations. Relative change in estimated mass (not true mass) was used in the assessments. In general, using "expected" values of nitrogen removal (scenario 3, which utilized avoidance and minimize approaches) was comparable to the baseline conditions represented in scenario 1. Very high or very low retention values provided less discernment among scenarios, while doubling concentrations resulted in only minor impacts to percent retention.

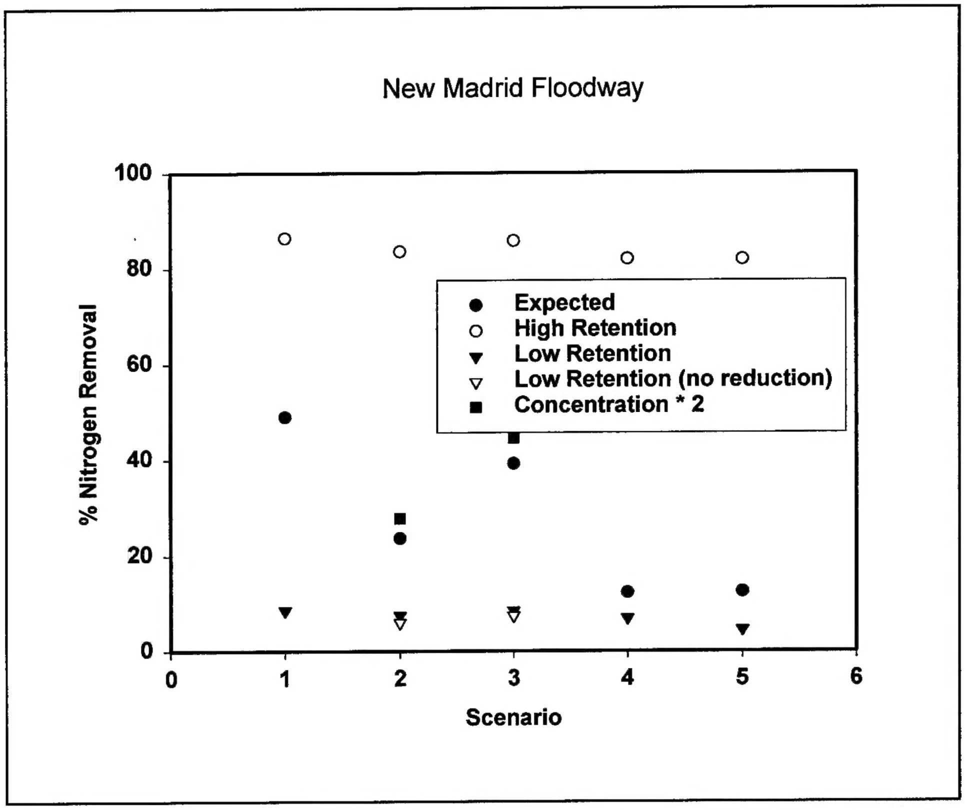


Figure 3. Estimated percent removal of nitrogen for various project alternatives

This approach lacks specific information on material processing of floodwaters by various land uses; however, it does allow a "relative" comparison of "potential" project impacts of alternative scenarios. Clearly more detailed assessment of material processing for each land use would provide much more detailed information on the actual quantity of material removed or transported but the cost (in time and dollars) to obtain this information would be extremely high.

**Site-specific Assessment.** A mass balance approach is currently being used to assess water quality functions of a permit application for fill of a wetland. The mass balance approach was designed to provide site-specific information of material retention and transport for quantifying potential losses associated with the fill activity. This information would also supplement qualitative assessments using the Indicator Value Assessment method (Hruby, Cesanek, and Miller 1995). Based on observations of site hydrology and inflow and outflow points, a monitoring program was developed to provide continuous measurements of groundwater elevation, elevation of surface waters, velocity at major inflow and outflow points, and selected water quality constituents in conjunction with 4-5 runoff events coincident with seasonal patterns. This approach requires extensive field work to establish and maintain sampling sites and coordinate collection of water samples relative to changes in the hydrograph associated with storm events. While automated equipment is available to collect the data and water samples, maintenance is a major concern and capital costs can be quite high. Sample preservation is also a problem with collection of water for multi-constituent analyses.

While the data are still under evaluation, results indicate a highly variable system that will yield mass balance estimates with broad error bars (Figure 4). Part of this variability was attributed to a lack of complete understanding of the site hydrology, equipment failure, and limited resources for more intensive sampling.

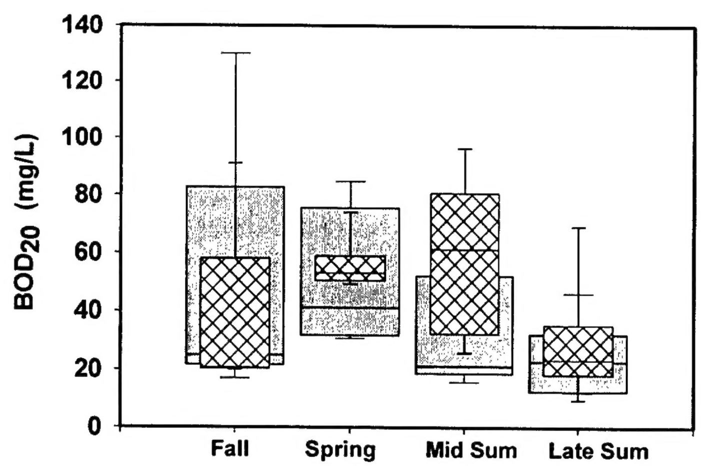


Figure 4. Distribution of biological oxygen demand concentrations during seasonal (fall, spring, mid summer, late summer) storm events at an inflow (gray boxes with wide cross hairs) and outflow (hatched boxes with narrow cross hairs). Values are before flow-weighting for mass balance estimates

This approach is cost- and labor-intensive but, if conducted appropriately, can provide quantitative information for determining water quality functions of wetlands. The ability to accurately account for the water budget and coincident material movement is critical to the application of this approach.

**CONCLUSIONS:** Kusler and Niering (1998) raise some interesting questions that are applicable to evaluating methods for assessing water quality functions of wetlands. Questions address such issues as scientific capabilities, resources, applicability, definition of assessment needs, policy implications, use in decision-making processes, and field tests of methods for accuracy, cost, and practicality. The authors suggest a return to the basics via open recognition of gaps in scientific knowledge, integration of regulators, policy-makers, and users into application of methods, field studies for evaluating accuracy, costs, and practicality, peer review, and, in general, a more holistic approach to application and improvement of existing methods at site-specific and watershed levels.

The most commonly used methods to assess water quality functions are qualitative, primarily due to time and resource constraints. Often, certain indicators used in other assessment approaches (e.g., redox conditions and soil chroma) provide sufficient indication of water quality processes such as metals cycling but are not sufficient for quantification. Site-specific data can be used to enhance qualitative assessments and support approaches such as "best professional judgment," but understanding and measuring the hydrology of the system is necessary to achieve a quantitative assessment. Needs for more detailed assessment at different spatial and temporal scales indicate that semi-quantitative methods, such as spreadsheets, are worth further consideration and need research and development to refine information used as input. Using flow-weighted concentrations from site-specific measurements in a mass balance approach is an option for quantifying water quality functions of wetlands but also requires knowledge of site hydrology. If sufficient information (e.g., nutrient retention/transformation rates) exists on representative systems, then a modeling approach can be used, but this approach also requires knowledge of site hydrology. These approaches can include references and indicators that have been or are being developed in wetland and other landscape assessment methods. Assessing water quality functions of wetlands also includes a consensus on applications of various methods.

Resource managers and regulatory agencies should identify those water quality functions that are most critical in the system being considered and how loss of each will impact the local, regional, or landscape system. Since not all water quality functions exist in every system and lost functions cannot always be replaced or mitigated, agencies and stakeholders may need to prioritize water quality functions. This approach can help guide decision-making for sound resource management.

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